USAELRDL Technical Report 2356

SOLID STATE S- AND X-BAND POWER SOURCES

V. Boxer

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UNITED STATES ARMY
ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY
FORT MONMOUTH, N.J.

SOLID STATE S- AND X-BAND POWER SOURCES

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DA Task Nr. 3A99-21-003-03

ABSTRACT

It is now possible to fabricate all semiconductor (devices) sources with usable microwave output power. Specifically, 2 watts of microwave power at S-band (3000 Mc) and 250 milliwatts at X-band can be obtained from such sources.

Sylvania Electronic Systems, Buffalo, New York, has fabricated engineering models of these components under Contract DA36-039-SC-87330. This report describes electrical measurements made on an X-band model at USAELRDL as part of the model-evaluation program. Spurious responses are shown to be at least 24 db below the primary output; stability is better than 0.0001 per cent.

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FORT MONMOUTH, NEW JERSEY

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SOLID STATE S- AND X-BAND POWER SOURCES

INTRODUCTION

Capability in the area of harmonic generation has been significantly increased as a result of application of the varactor diode to this task. It is now possible to fabricate all semiconductor (devices) sources with usable microwave output power. Specifically, it is possible to obtain watts of microwave power at S-band (3000 Mc) and hundreds of milliwatts at X-band (9000 Mc) from such sources.

Sylvania Electronic Systems, Buffalo, New York, has developed and fabricated engineering models of these components under Contract DA36-039-SC-87330. This report describes electrical measurements made on an X-band model at the USAELRDL as part of the model-evaluation program. The circuit description and illustrated photographs of the circuit modules are included for completeness, and may also be found in the quarterly reports for the contractual program.

The objectives of the above development program were to provide relatively compact, stable, microwave power sources for S- and X-bands. The S-band unit was to be capable of providing two watts of CW rf power, while the X-band source would provide in excess of 200 milliwatts of similar rf power. This was accomplished by a series of frequency multipliers employing silicon transistors and varactor diodes in thermally compensated circuits driven by a crystal-controlled oscillator. The S-band unit consists of 10 such stages, whereas the X-band version uses 12.

CIRCUIT DESCRIPTION

The harmonically related VHF exciter chain, shown in Figs. 1, 1A, and 1B, common to both power sources, contains seven transistors, uses lumped circuits, and terminates at 140.6 Mc with a power output of 12 watts, and an overall efficiency of 43 percent. From that point on the multiplier stages employ varactor diodes in appropriate microwave mounting, biasing, and matching networks to complete the chain to the desired output frequency (Fig. 2). The actual doubling efficiency versus frequency is shown in Figs. 3 and 4.

The unit is approximately 6 inches high, 4-1/4 inches wide, 6-1/2 inches deep, and weighs 9.9 pounds with a volume of about 170 cubic inches. It could conceivably be packaged within 80 cubic inches at a maximum weight of four pounds by incorporating in it circuits where protective transistor breakers would not be required, and a maximum heat transfer could be effected by appropriate mounting in the chassis container.

At the present writing, solid-state varactors provide the most efficient means of converting the low frequency to the desired microwave frequency. The circuitry design of the solid-state generator takes into consideration maintenance of optimum power levels under conditions of temperature change. A thermistor in the base circuit of the power driver improves the output versus the temperature characteristics of the power amplifiers. The negative temperature coefficient of the thermistor element controls the resistance in the base circuit of the transistor, and thus controls the power gain of the amplifier. At low temperatures, the thermistor provides increased base

resistance which limits the power gain of the driver stage. As temperature increases, the base resistance decreases and provides increased drive power to the power amplifiers. Thus, the output from the power amplifiers remains constant over a temperature range determined by the thermistor characteristics and the high temperature characteristics of the power amplifier transistors.

For handling power input levels on the order of 12 watts, a balanced-pair varactor doubler with self-bias is used. This configuration is relatively insensitive to load variations and is able to minimize the stress levels imposed on the varactors. Phasing of signals may be controlled in such a way as to permit only even harmonics to be produced. Since the second harmonic is taken from the center tap of the balanced transformer, fundamental and third harmonic traps are not required. All the above advantages offset the requirements of two varactors per stage and make this circuit superior to the single varactor configuration.

The third, fourth, fifth and sixth doublers can be better understood, perhaps, by referencing their photographs in Figs. 5, 6 and 7. The input circuit for the third doubler consists of a pi matching network and a coaxial capacitor. The output circuit consists of a single matching stub and a quarter wave resonant cavity. The input to the fourth doubler is matched to the output of the third doubler cavity through a double stub matching network, a coaxial capacitor, and a second harmonic trap. The short-circuit stub in the next doubler (S- and C-band), a quarter wavelength to the fundamental, located at the input side of the varactor, prevents a reflection of second harmonic power from passing back to the fundamental source. The open-circuit stub, also a quarter wavelength to the fundamental, located on the output side of the varactor, prevents fundamental power from passing on to the output. Double stub matching networks at the input and output of the multiplier insure a match to a 50-ohm impedance level. Although not shown clearly in the photographs, bias is applied to the varactor by a fine (high impedance) wire located between the open-circuit stub and the varactor. A capacitance blocking joint is inserted in the center conductor between the varactor and the double stub tuner to prevent the output double stub tuners from short circuiting the bias voltage. In the C- to X-band doubler, the varactor is located directly across a section of RG52/U waveguide. Second harmonic power is prevented from returning to the input by a short-circuit stub, a quarter wavelength to the fundamental, located at the input side of the varactor. The adjustable short circuit located at the output side of the varactor provides series tuning of the varactor at the fundamental frequency. Direct-current bias is applied to the center conductor of this circuit with an appropriate dc block located between the bias joint and the short circuit. Matching of the varactor to the waveguide is accomplished by an adjustable waveguide short circuit. A doubler stub tuner at the input to the multiplier provides matching to a 50-ohm input impedance. This completed unit is shown in Figs. 8 and 9.

CHARACTERISTICS

Electrical Characteristics

The electrical characteristics for both types of generators are listed below:

	S-band	X-band
Power Output	2 watts	250 mw
Frequency	2250 Mc	9001.25 Mc
Stability	0.0001%	0.0001%
Spurious Output	-30 db	-24 db or better
Efficiency:		
without circuit breakers	7.0%	0.9%
with circuit breakers	7.0%	0.7%
Input supply voltage	50 vdc	50 vdc

Spurious Response

A tunable X-band filter used in conjunction with an X-band frequency meter helped determine the magnitude and frequency of spurious responses. These turned out to be located at 9.865, 9.093 and 9.165 kMc. The one located nearest the desired frequency--the second mentioned, showed a power level below 0.01 mw in the test setup shown on the block diagram. The others indicated powers below 0.02 mw.

These potentially objectionable frequencies are a minimum of 24 db below the desired frequency.

Stability

The short-term checks performed with the source, counter and transfer oscillator indicate that the power generator is capable of maintaining a stability of 0.0001 percent. The curve on the graph of a number of 15 readings, levels off at a point to show a stability of 5 parts per 10 million for 45 seconds (Fig. 10). The curve for a series of readings over a five-hour period also delineates a pattern of terminal stability toward 75 parts per 10 million per hour (Fig. 11).

Since the stability is limited by that of the driving source, the generator could be improved at the cost of lowered efficiency by utilizing an oven-controlled crystal in the oscillator stage. The additional expenditure of a watt or two may be justified in the case where frequency stability is a critical requirement.

Frequency measurements conducted by the contractor with a special 46.877 Mc crystal indicated a stability of 0.0001 percent over a temperature range of 25° to 35°C. The long-term drift was less than 0.00003 percent (permanent change). Over a period of several hours, the oscillator maintained frequency within 5 cycles or 0.00001 percent at a temperature of 30 ± 1°C.

A delay of a minute or so is encountered from turn on to the time a stable CW signal with the minimum of spectrum clutter is obtained. During this time, the following sequence may be observed on a spectrum analyzer. First, noise alone is visible followed by a short interim in which the carrier plus sidebands are building up. This is followed by shifting and

diminishing sideband energy until the complete stabilization of the carrier occurs, and noise and clutter disappear.

Sideband energy can be affected by primary supply voltage variation. Figures 12 through 18 show changes in spectrum caused by voltage variations. Variations of from 3 to 5 volts resulted in the shifting of energy from the main carrier to the sidebands, even to the suppression of the main carrier. This is partially due to the fact that all circuits are supplied by one voltage source using suitable voltage dividers and diodes. Thus the latitude permitted by individual supplies is curtailed with one voltage source. Therefore, to present a good clean signal, a well-regulated supply is recommended.

Shock

While no attempts were made to evaluate this type of generator on a package tester, cursory operative tests in this Laboratory appear to establish the superior characteristics exhibited by the solid-state source (in this case--an X-band model) over its electron tube counterpart, the klystron.

A photograph taken from a display of spectrum analyzer (Fig. 19) shows the noise and frequency shift resulting from tapping a klystron with a wooden pencil approximately seven inches long. A similar photograph (Fig. 20) shows the relative insensitivity to shock when the solid-state source is tapped with a two-ounce ball-peen hammer.

INSTRUMENTATION

Frequency Measurement

The transfer oscillator generates a stable signal, adjustable in frequency from 100 to 200 megacycles, which is continuously monitored to 1 part per million accuracy by the frequency counter. Harmonics of the transfer oscillator are then compared in an internal mixer with the frequency to be measured, using a self-contained oscilloscope to observe the difference frequency. By suitable adjustment, a zero beat can be obtained between a transfer oscillator harmonic and any unknown frequency applied to the input. The unknown is then a determined multiple of the reading on the frequency counter which can be read as close as 2 parts per 10 million.

SUMMARY AND CONCLUSION

The feasibility of stable, reasonably compact, solid-state S- and X-band power sources has been demonstrated. The key criteria of stability, power, and reliability have been established for potential military use in such diverse applications as parametric amplifier pumps, local oscillators, beacons, portable transmitters, and airborne end items.

Where stability requirements are more stringent, the oven-controlled crystal oscillator may be employed. It is conceivable that techniques arising from this study may permit improved generators of considerably greater bandwidth in the immediate future.

Neglecting heating losses due to dissipation by the varactor spreading resistance and ionization effects in the semiconductor material, the power

handling capability of a varactor multiplier diode is proportional to the square of the reverse breakdown voltage of the varactor. The efficiency is proportional to the diode cutoff frequency or Q. The new 100-volt-high cutoff frequency varactors have considerably greater power handling capability than their 30-volt predecessors. This means that the high power output and efficiency previously available only in HF and UHF multipliers can now be realized at microwave frequencies up to the X-band region.

Varactor power handling limits have been raised steadily at a concomitant rate with high power, high frequency, transistor development. This combination will extend the present frequency limits, and permit rapid development of pulsed sources. Specific devices under current development include 10-watt and greater dissipation varactors, 100 Mc, 25-watt transistors, and pulsed sources of 10-watt capability at C-band.

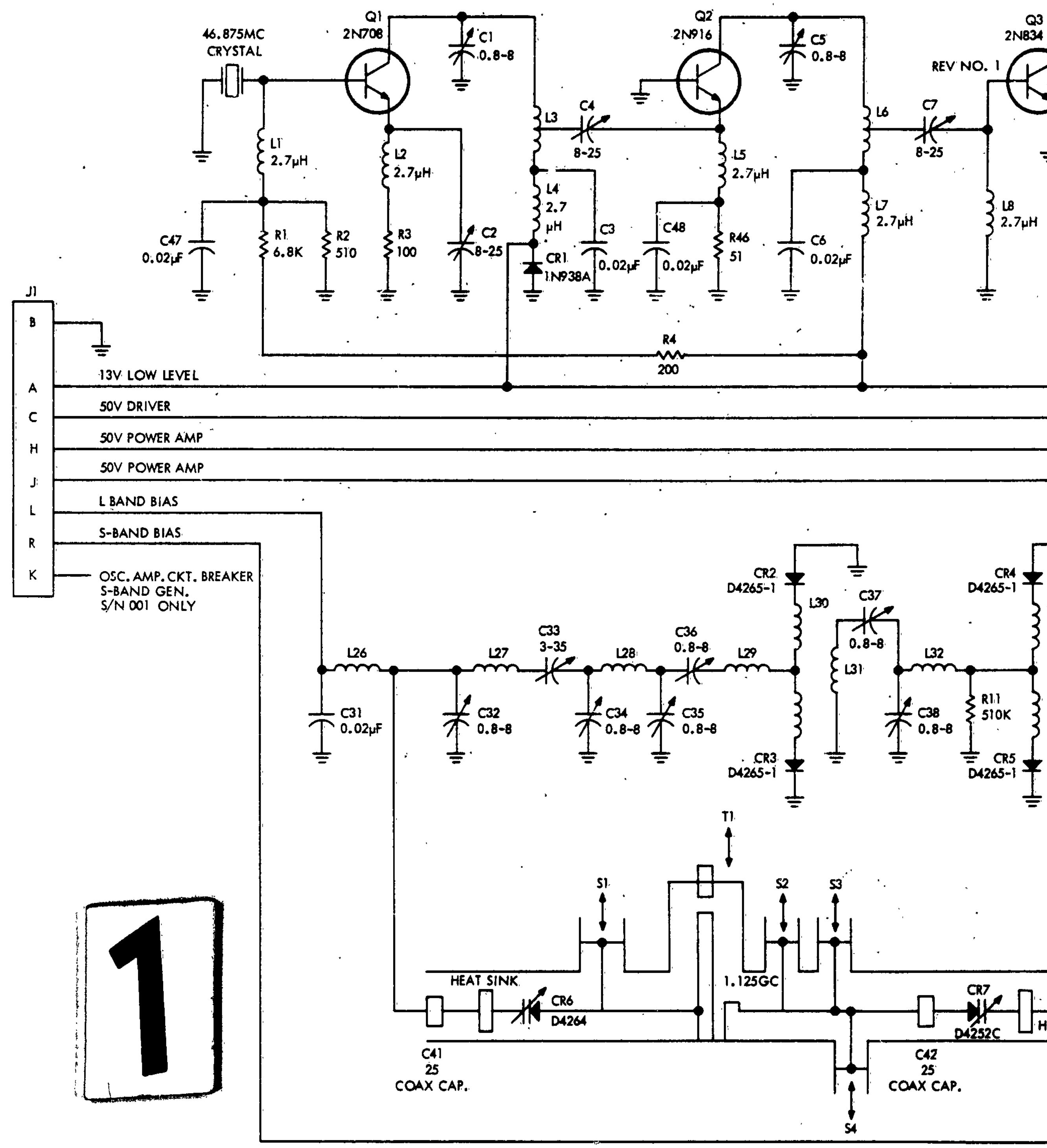
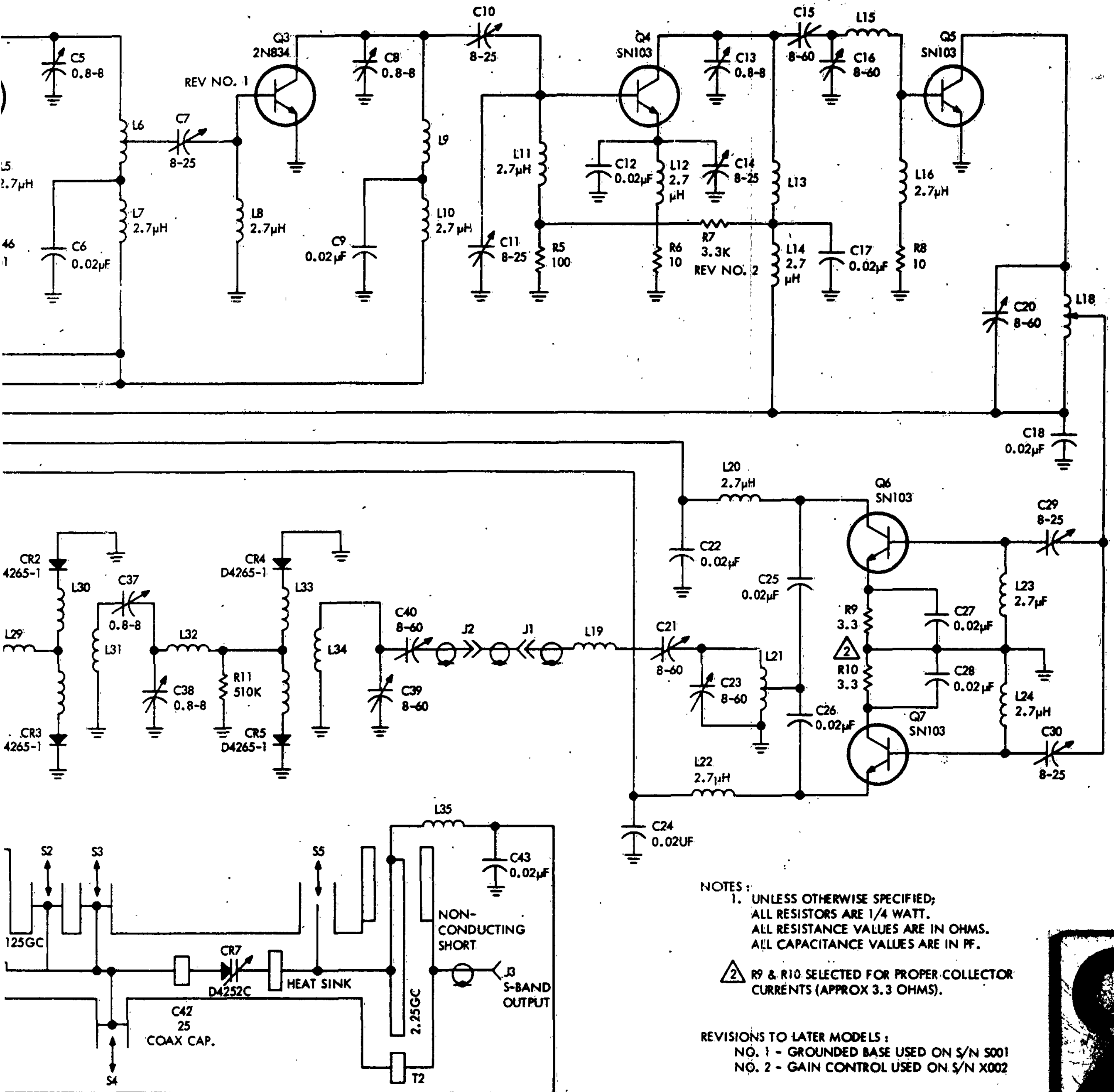


Fig. 1 SCHEMATIC HARMONIC EXCITER CHAIN

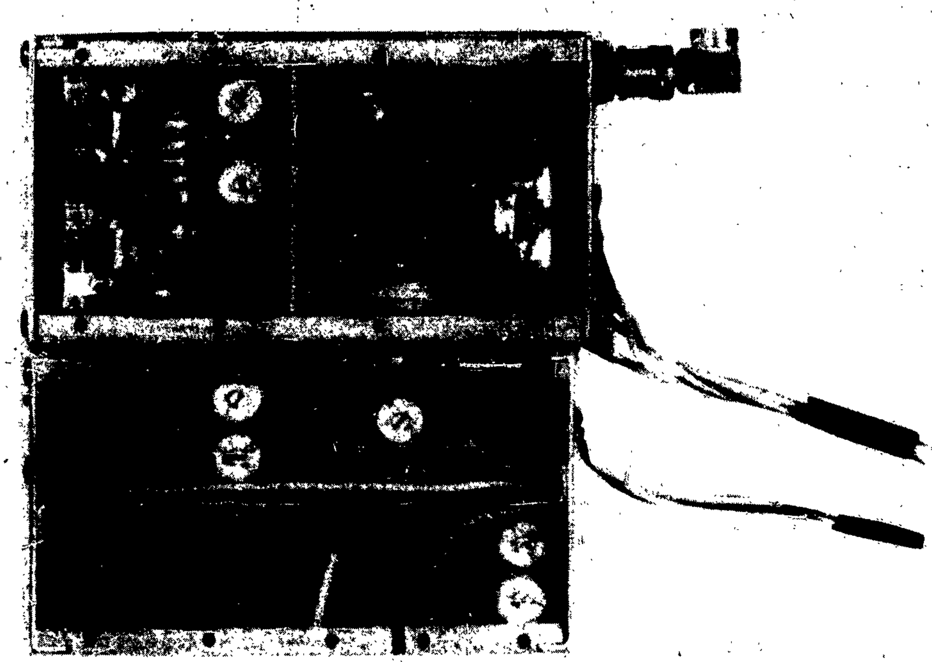


NOTES:
1. UNLESS OTHERWISE SPECIFIED;
ALL RESISTORS ARE 1/4 WATT.
ALL RESISTANCE VALUES ARE IN OHMS.
ALL CAPACITANCE VALUES ARE IN PF.

2 R9 & R10 SELECTED FOR PROPER COLLECTOR CURRENTS (APPROX 3.3 OHMS).

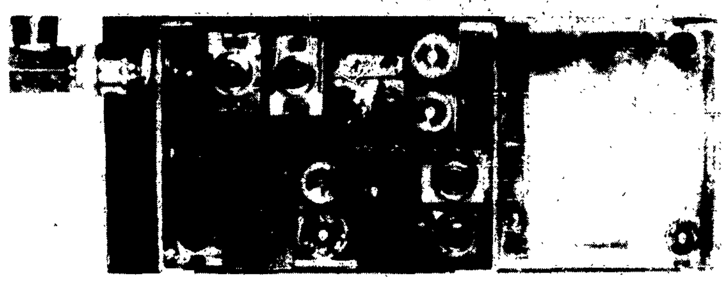
REVISIONS TO LATER MODELS:
NO. 1 - GROUNDED BASE USED ON S/N S001
NO. 2 - GAIN CONTROL USED ON S/N X002

ATIC HARMONIC EXCITER CHAIN



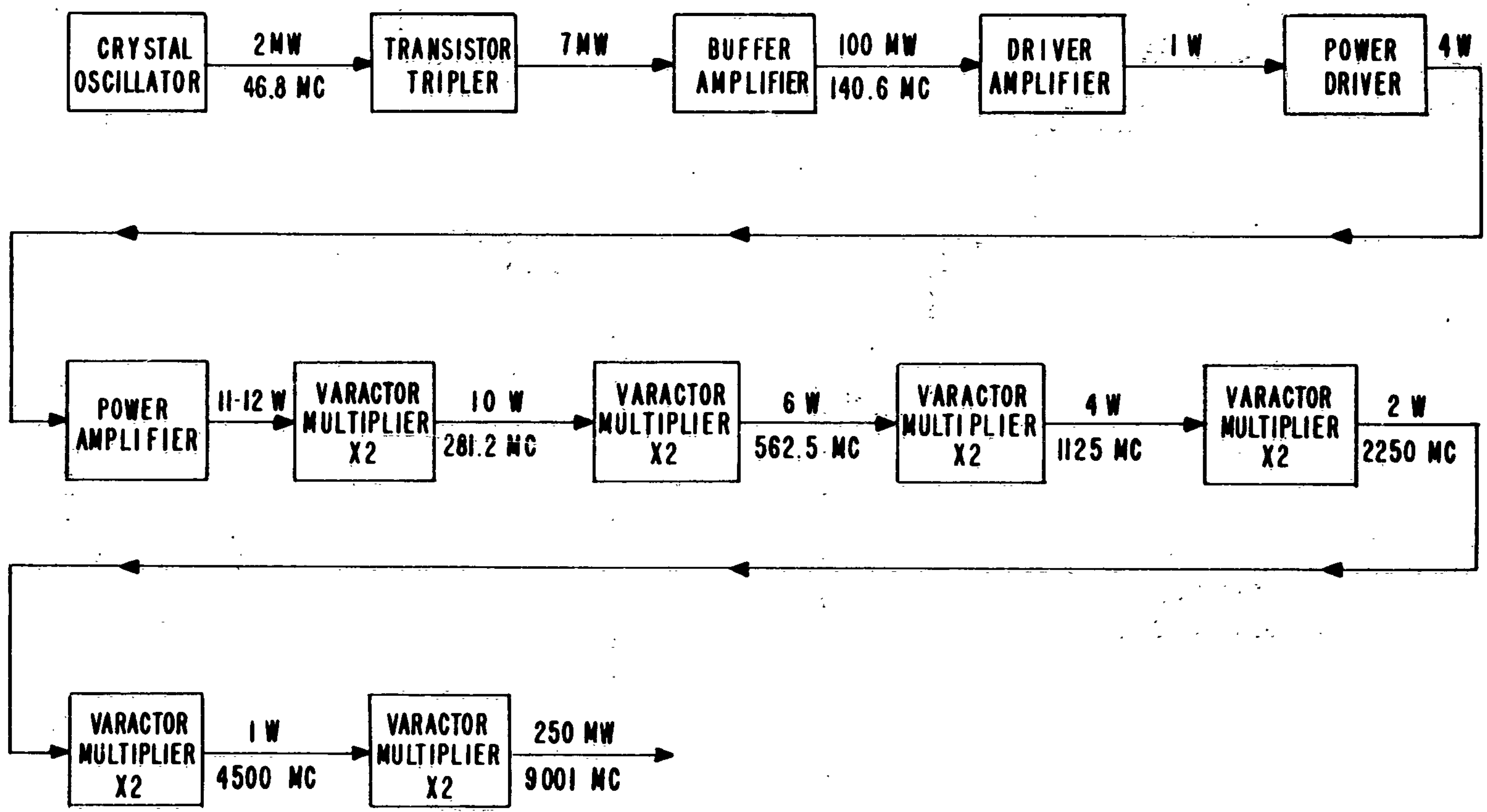
UNDER CHASSIS VIEW

FIG. 1A

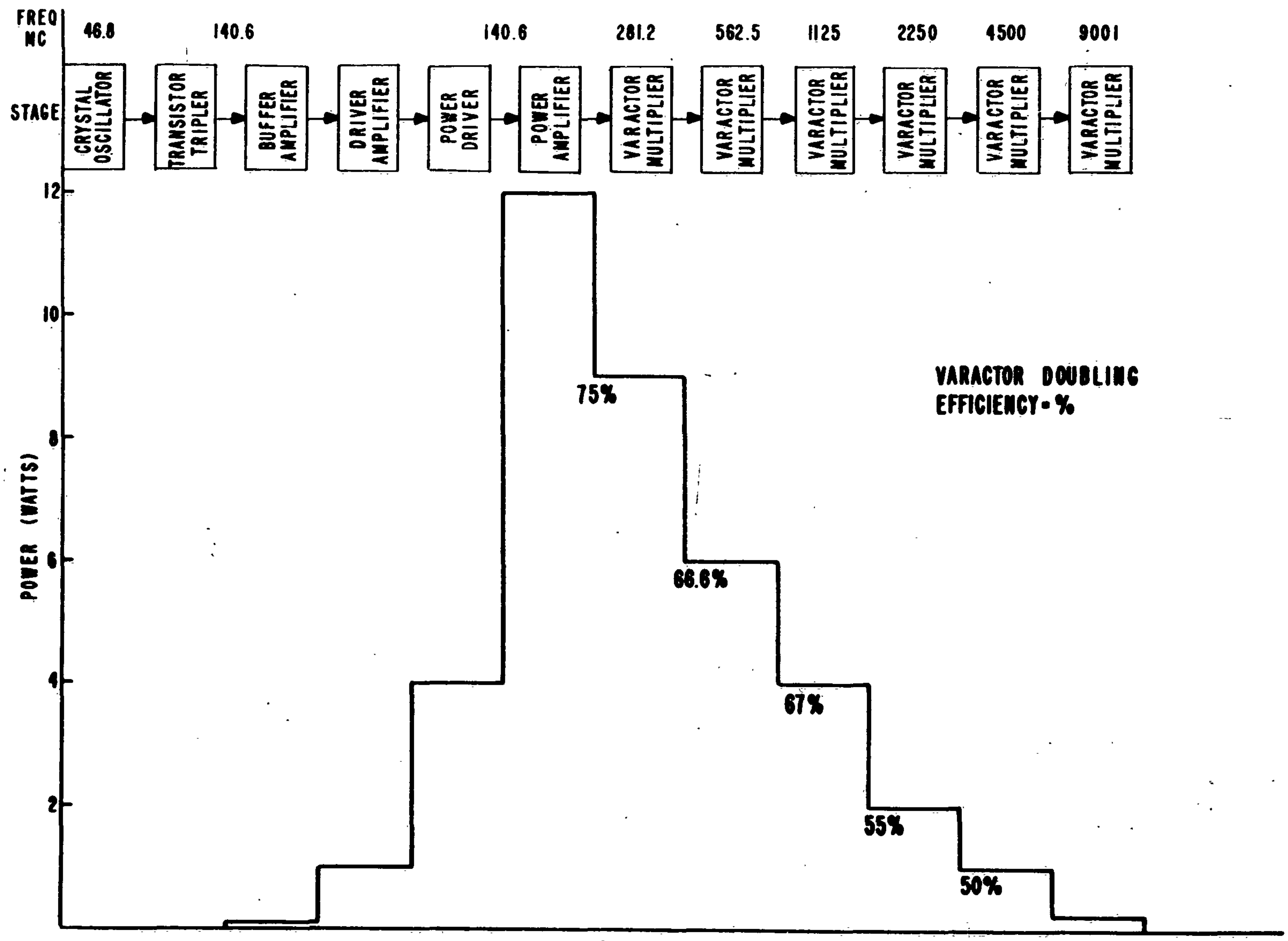


MODULE VIEW

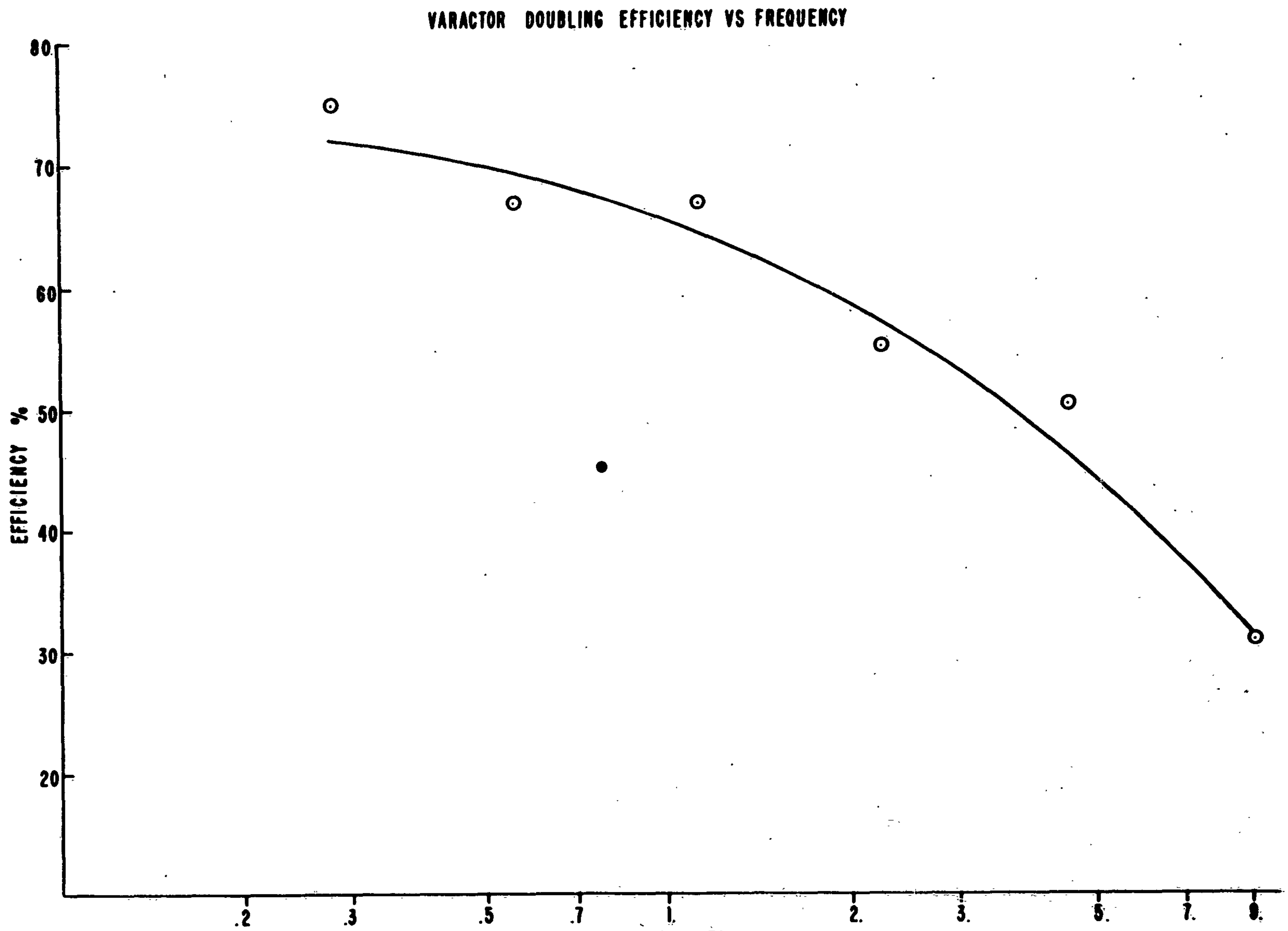
FIG. 1B

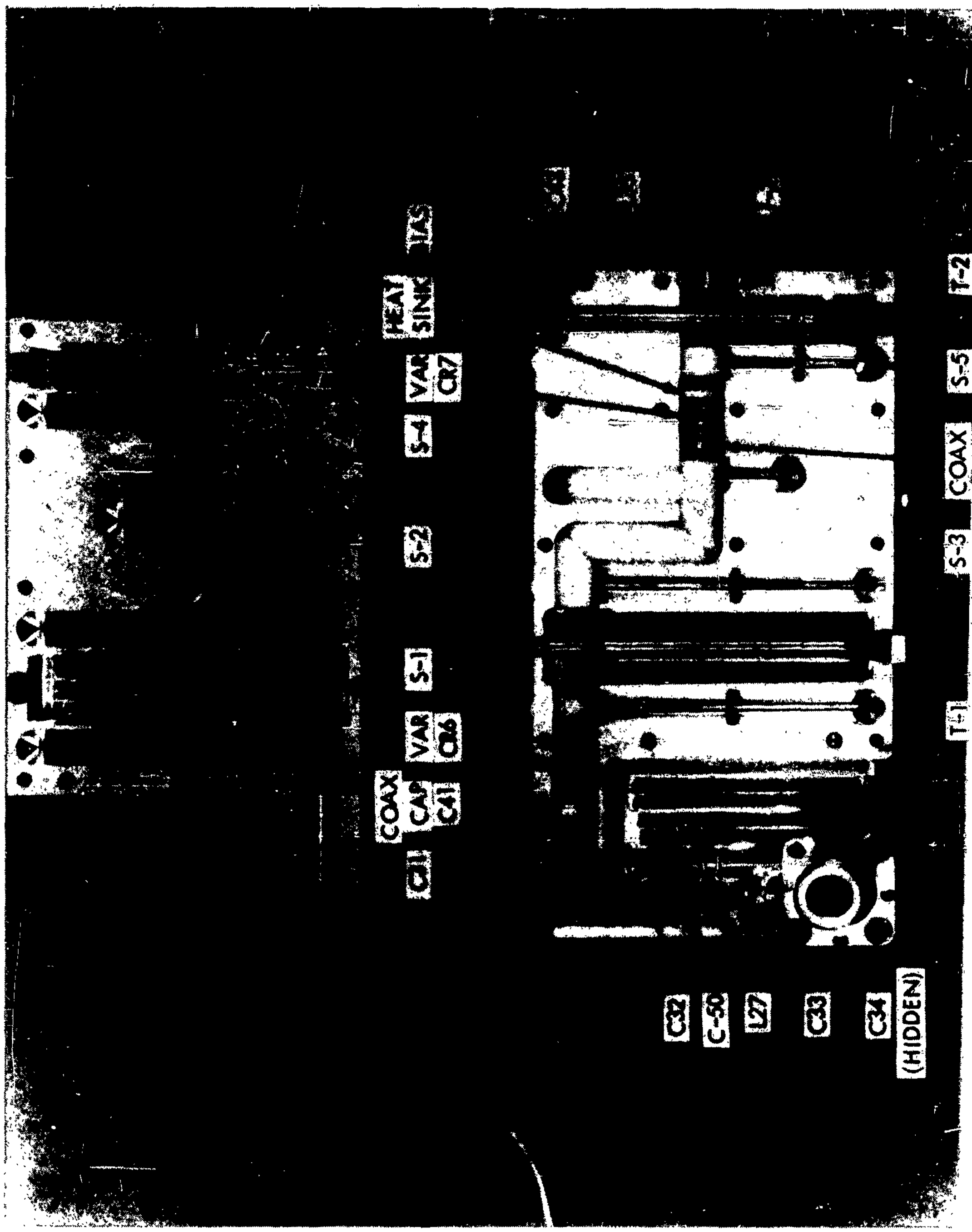


S-X BAND POWER GENERATORS
BLOCK DIAGRAM
FIG. 2



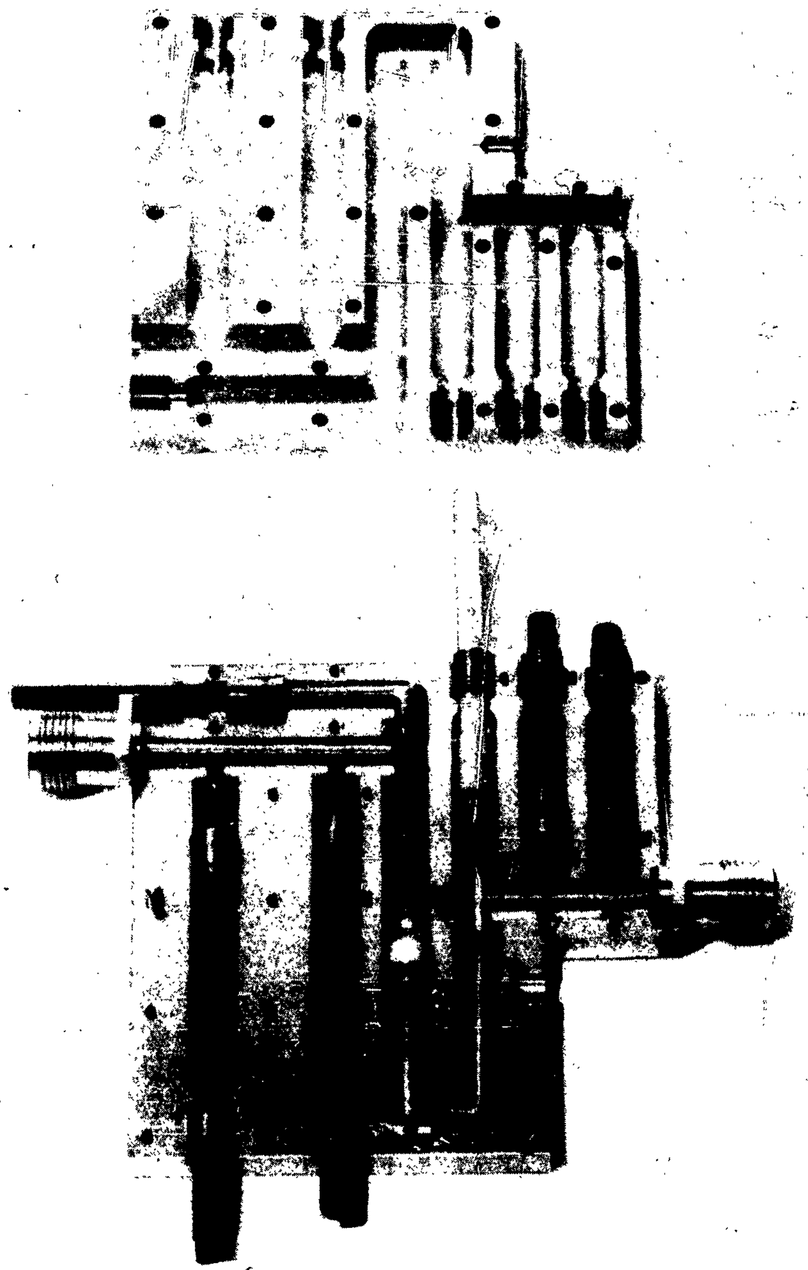
X-BAND POWER GENERATOR
FIG. 3


VARACTOR DOUBLING EFFICIENCY VS FREQUENCY
EFFICIENCY %
80
70
60
50
40
30
20
.2
.3
.5
.7
1.
2.
3.
5.
7.
9.
KILOMEGACYCLES
FIG. 4



THIRD AND FOURTH DOUBLERS

FIG. 5



S TO C BAND DOUBLER

FIG. 6

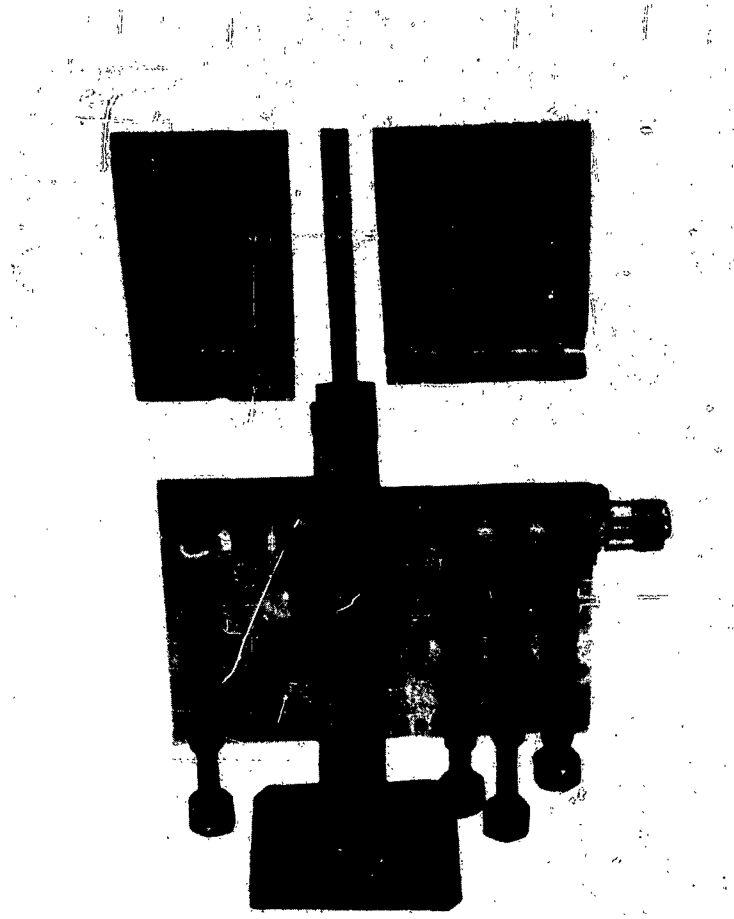


FIG. 7

C TO X BAND DOUBLER

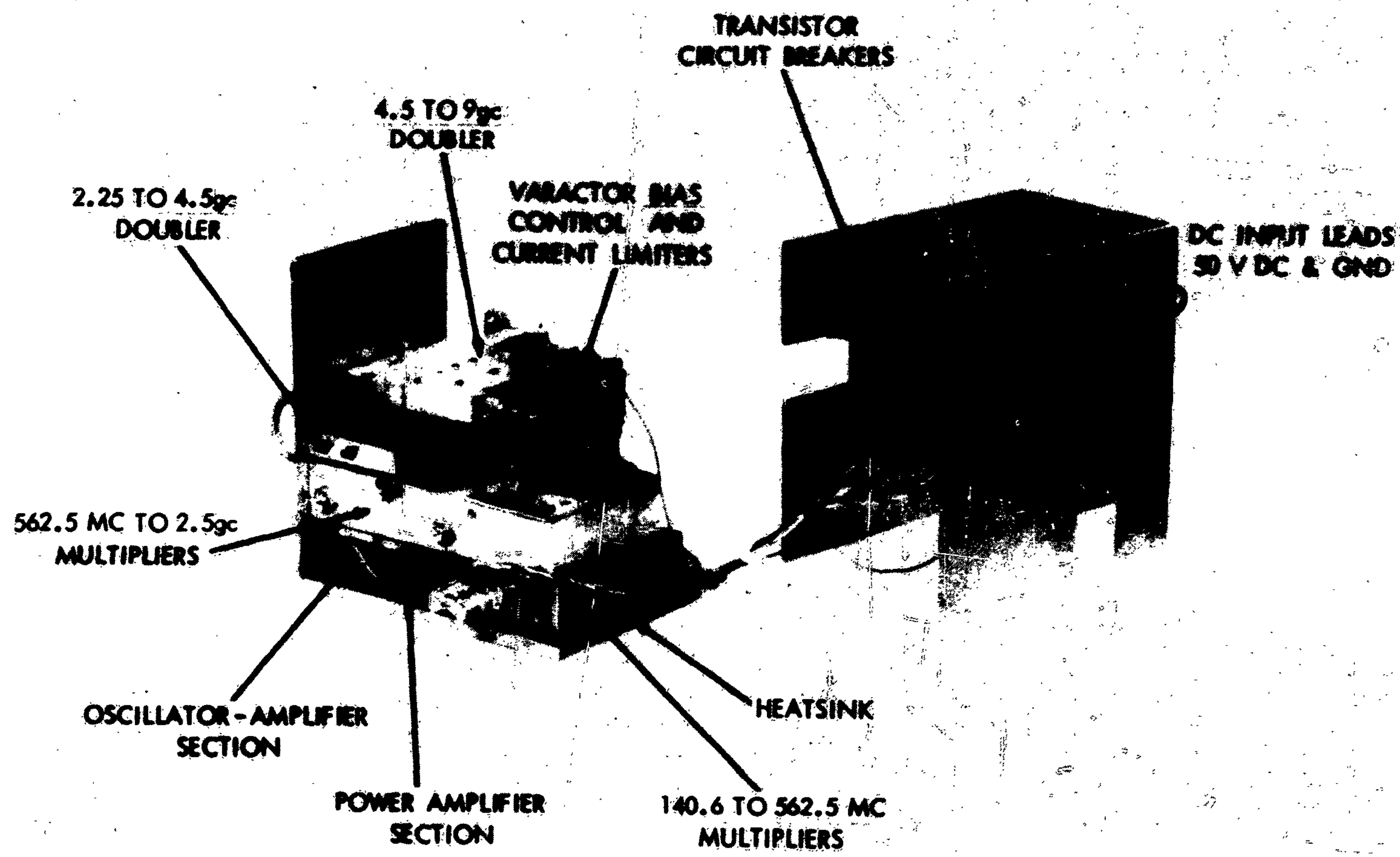
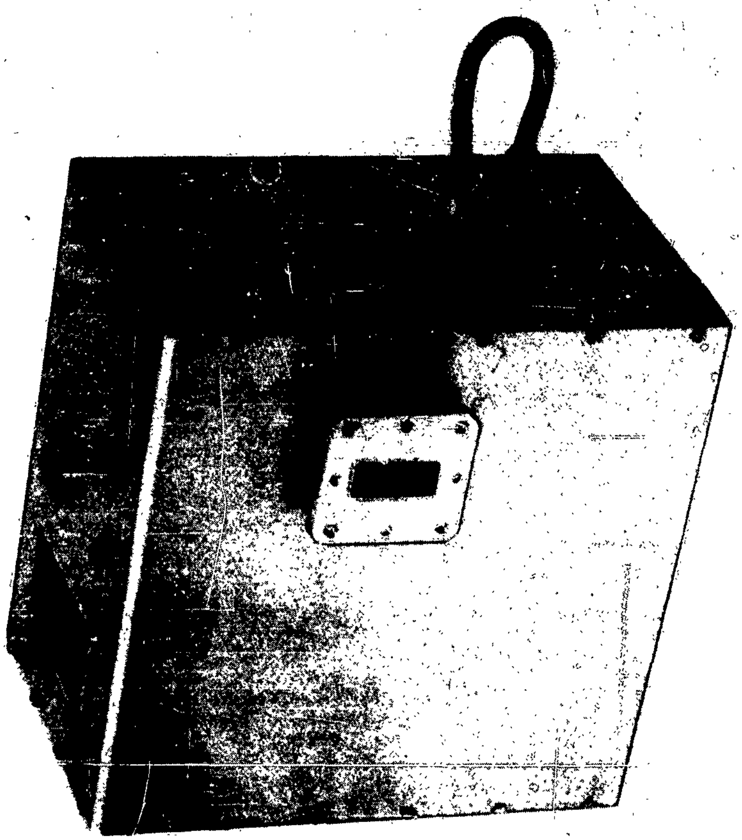


FIG. 8 X BAND POWER GENERATOR



COMPLETE X BAND POWER GENERATOR

FIG. 9

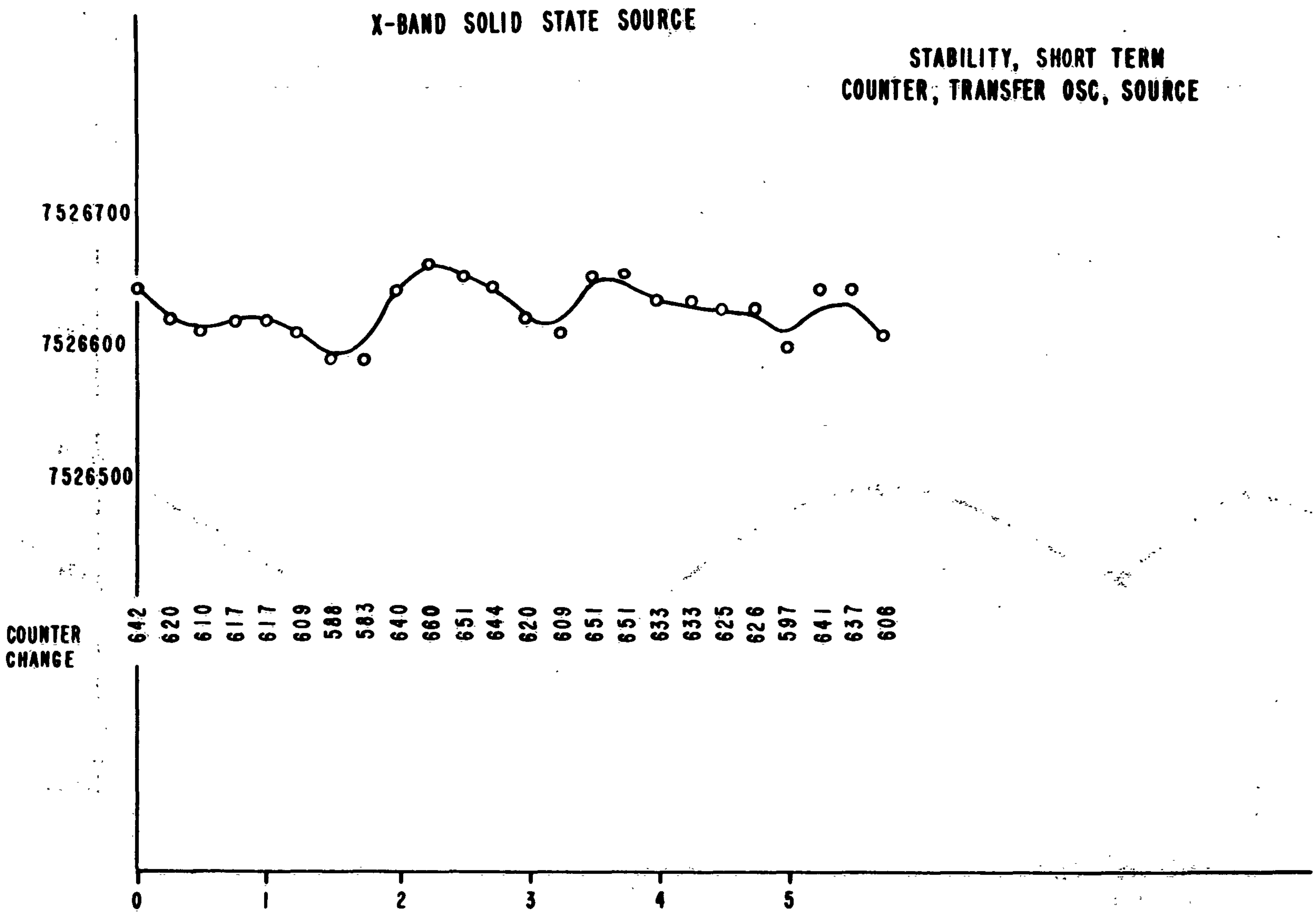

X-BAND SOLID STATE SOURCE
STABILITY, SHORT TERM
COUNTER, TRANSFER OSC, SOURCE
7526700
7526600
7526500
COUNTER CHANGE
642 620 610 617 617 609 588 583 640 660 651 644 620 609 651 651 633 633 625 626 597 641 637 606
0 1 2 3 4 5
MINUTES

FIG. 10

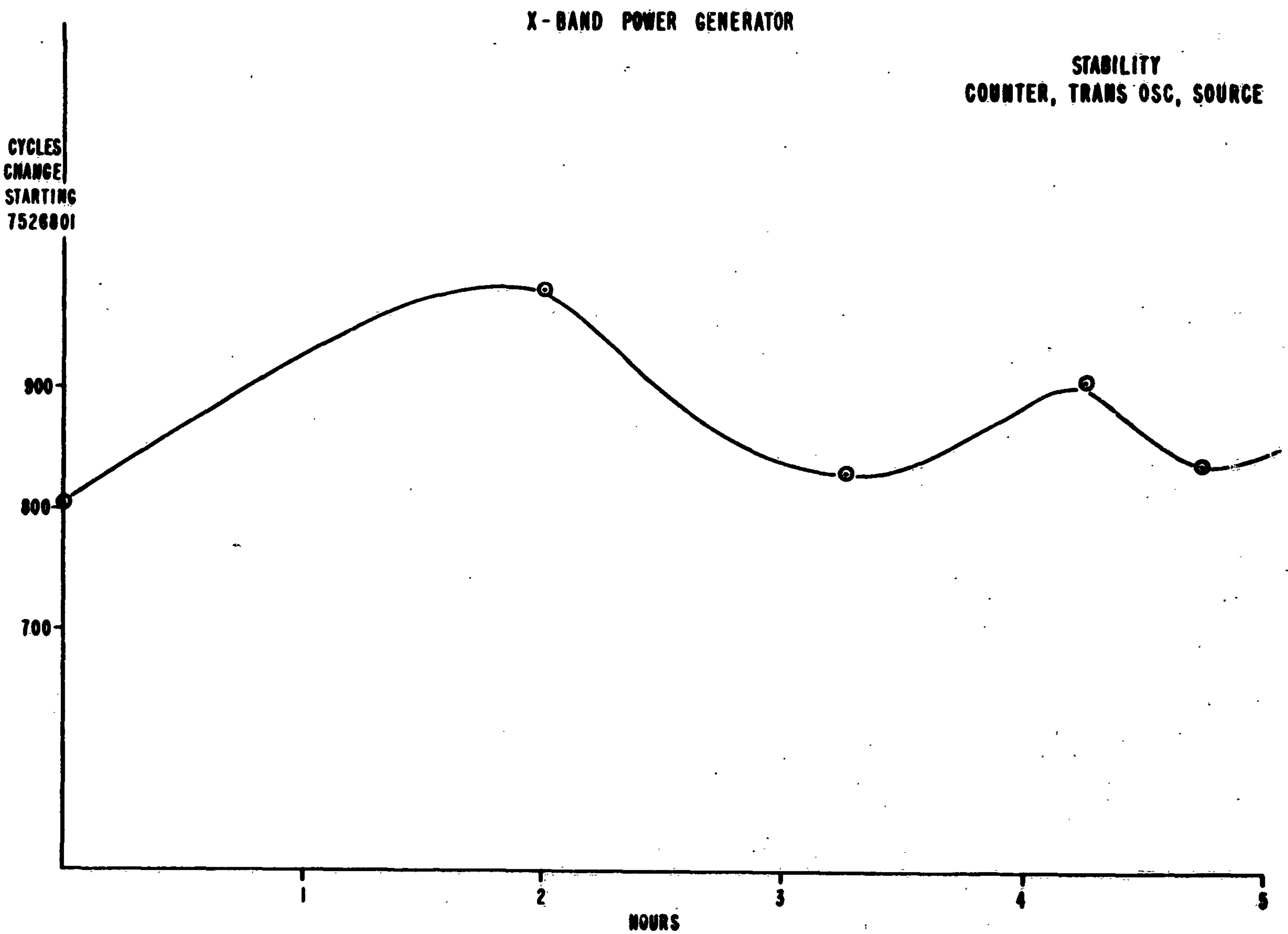

X-BAND POWER GENERATOR
STABILITY
COUNTER, TRANS OSC, SOURCE
CYCLES
CHANGE
STARTING
7526801
900
800
700
1
2
3
4
5
HOURS

FIG. 11

FIG. 12 SPECTRUM OF SOLID STATE SOURCE SHOWING THE SIDEBAND APPEARANCE WHILE CHANGING THE SUPPLY VOLTAGE

FIG. 13 SPECTRUM OF SOURCE WITH SUPPLY VOLTAGE MISADJUSTED

FIG. 14 SPECTRUM OF SOURCE SHOWING SIDEBAND DISPERSION DURING "WARMUP" (APPROXIMATELY FIRST MINUTE)

FIG. 15 CARRIER SUPPRESSED WITH LOW SUPPLY VOLTAGE

FIG. 16 SPECTRUM DURING "WARMUP" SHOWING EQUAL SIDEBANDS

FIG. 17 PEAKED CARRIER WITH SUPPLY VOLTAGE CHANGE

FIG. 18 NOISY SPECTRUM FROM HIGH SUPPLY VOLTAGE

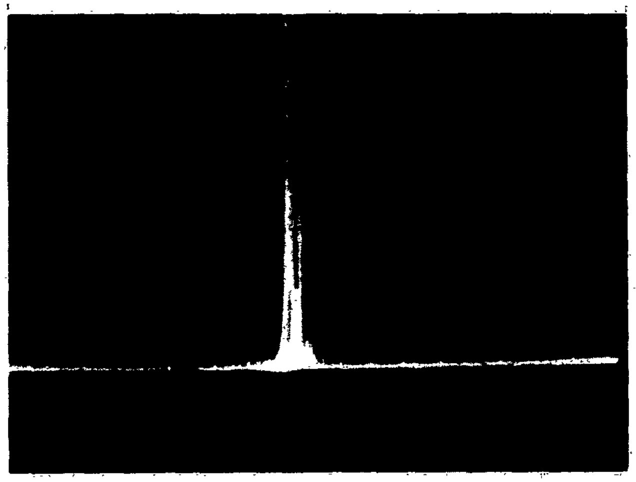


FIG. 19 NOISE FROM KLYSTRON WHILE BEING TAPPED WITH WOOD OFFICE PENCIL

FIG. 20 NOISE FROM SOLID STATE SOURCE WHILE BEING TAPPED WITH 2 OUNCE BALL PEEN HAMMER

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by V. Boxer, January 1963, 20 p. incl. illus.
(AELRDL Technical Report 2356)
(DA Task 3A99-21-003-03) Unclassified report

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2. Generator, Solid State
3. Frequency Multiplication

I. Boxer, Victor
II. Army Electronics Research and Development Laboratory, Fort Monmouth, N. J.
III. DA Task 3A99-21-002-03

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